Advanced Utility Mercury-Sorbent Field-Testing Program

Semi-Annual Technical Progress Report

October 1, 2003 – March 31, 2004

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Abstract

This report summarizes the work conducted in the first half year (October 1, 2003 through March 31, 2004) of the project entitled Advanced Utility Mercury-Sorbent Field-Testing Program. The areas of the project addressed in this report are in Phases I, II, and III of the program. Specifically, the topics discussed are the project plan development, the equipment preparation, and the qualification testing and support activities.

The highlight of the document is the presentation of the results from the hot-side electrostatic precipitator (ESP) qualification testing conducted at the Duke Power Cliffside Plant. This was the first successful use of sorbents to capture mercury in the high temperatures present in this type of application. The results indicate a potential for Sorbent Technologies brominated sorbents (B-PAC™) sorbents to reduce the mercury emissions of boilers equipped with hot-side ESPs.

The significant accomplishments in the past half year were discussed along with problems encountered and plans for the next half-year.

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Introduction

The **Advanced Utility Mercury-Sorbent Field-Testing Program** project is divided into six phases as follows:

Phase I:	Project Plan Development
Phase II:	Equipment Preparation
Phase III:	Qualification Testing & Support Activities
Phase IV:	Field Trial at Detroit Edison’s St. Clair Plant
Phase V:	Field Trial at Duke Power’s Buck Station
Phase VI:	Reporting & Technology Transfer Activities

This report details the progress made on Phases I, II, and III during this first half-year of the project.

Executive Summary

This report summarizes the work conducted in the first half-year (October 1, 2003 through March 31, 2004) of the project entitled Advanced Utility Mercury-Sorbent Field-Testing Program (Cooperative Agreement No. DE-FC26-03NT41990). The areas of the project addressed in this report are in Phases I, II, and III of the program. The first phase to be completed was the development of the overall project plan.

Phase II covered preparation of the project equipment. The design of the sorbent preparation systems and sorbent injection system were completed this project period. Equipment for these activities was designed and ordered and should all be assembled and operating during the next half-year period. The mercury sampling and measurement equipment was also designed and selected, and ordered from PS Analytical, a project partner.

Phase III covers the project's qualification testing and support activities. Qualification testing is preliminary testing to select the strategies and sorbents to be used at the project's long-term trial sites.

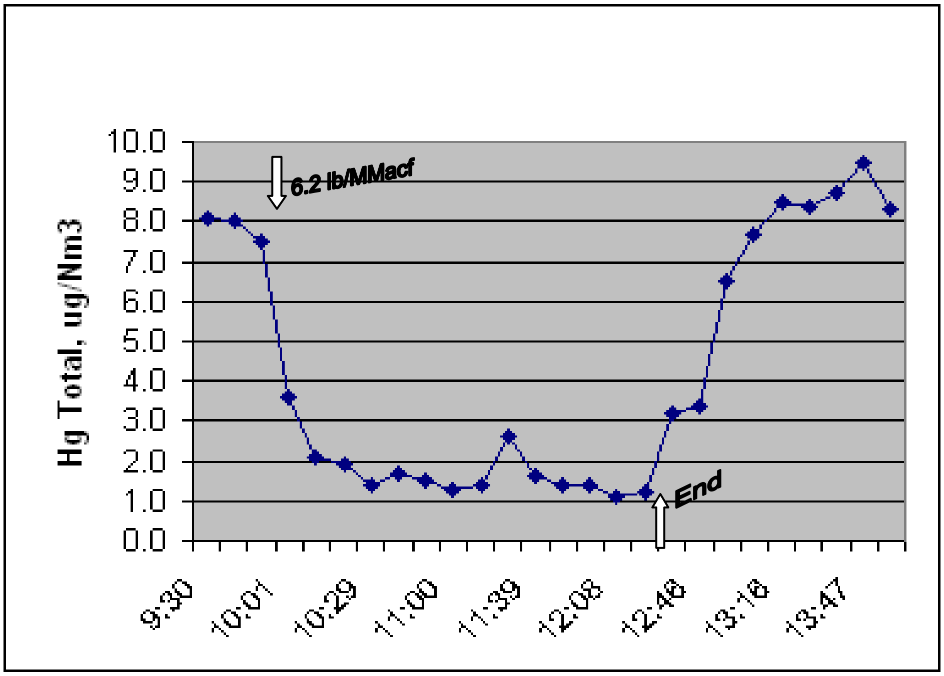
The project's first long-term testing site is Detroit Edison St. Clair Plant, which primarily burns a subbituminous coal and has a cold-side ESP. During this project period small-scale injection tests were performed with various brominated powdered activated carbons (B-PAC) by Sorbent Technologies at its pilot plant, which uses a simulated flue gas. In addition, subcontractor Apogee Scientific tested a number of B-PAC variations on a slipstream of actual subbituminous-coal flue gas at the We Energies Pleasant Prairie Plant, which hosted the first full-scale DOE activated carbon injection trials. In both of these test programs Sorbent Technologies' B-PAC sorbents exhibited significantly higher mercury performance than the Norit Darco FGD plain "yardstick" carbon.

The highlight of this report is the presentation of the results from the hot-side ESP qualification testing conducted at the Duke Power Cliffside Plant. For these short-term tests, a temporary small-scale injection system was provided by Sorbent Technologies, while mercury S-CEMs were provided and operated by Western Kentucky University, another project partner. Ontario Hydro Method mercury speciation tests were performed by Trigon Engineering Consultants.

This was the first successful use of a sorbent to capture mercury at the high temperatures of a hot-side ESP. The very short-term tests demonstrated a potential for brominated carbon sorbents to reduce the mercury emissions of boilers equipped with such hot-side ESPs. At least 40% mercury removal was indicated at normal operating conditions and at least 80% mercury removal was achieved at low load, as shown in the following figure. Consequently, project participants agreed to proceed with the project's longer-term larger-scale hot-side ESP tests at Duke's Buck Plant.

These results were achieved with a sorbent not specifically designed for use in a hot-side application. It is possible that even better mercury removal results can be achieved by optimizing this sorbent specifically for high-temperature use.

Duke Power Cliffside Plant Hg S-CEM Curve for Low Load Trial on 9/18/03



There has been a problem in finalizing the site location for the brominated carbon preparation system for the upcoming full-scale, long term St. Clair Plant trials. Plans for the next half-year call for the completion of the equipment preparation work and the beginning of the trials at the St. Clair Plant.

Experimental

Phase I: Project Plan Development

The project plan had not been finalized when the award contract was granted on October 1, 2003. The main portions to be negotiated were the Limited Data Rights Agreement and the Statement of Project Objectives. Finalization of this plan was an iterative process among all of the parties. An Amendment to the Cooperative Agreement which included the Statement of Project Objectives was signed by both DOE Contracting Officer and Sorbent Technologies Corporation Project Director by December 29, 2003. This completed the Phase I planning of the project.

Phase II: Equipment Preparation

The equipment preparation activities are divided into three tasks. Task 2 covers preparation of the sorbent injection system; Task 3, the mercury sampling and monitoring equipment; and Task 4, the sorbent preparation system. All of the tasks are currently underway and a status report is provided in this section.

Sorbent Injection System

The functions of the sorbent injection system are:

1. To provide for sorbent loading to a day storage hopper from either super sacks or pneumatic trucks.

2. To deliver the sorbent from the day storage hopper to a feeder system hopper.

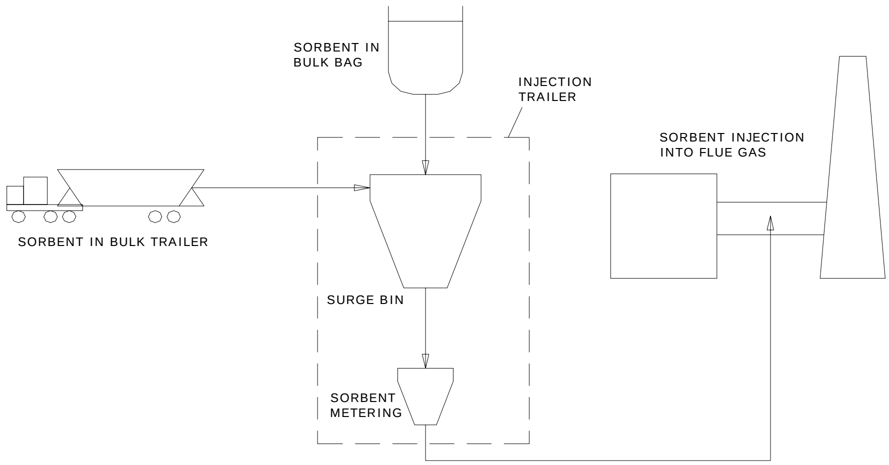
3. To gravimetrically feed sorbent at selected rates into an eductor injection system.

4. To provide dilute phase conveying of the sorbent through the sorbent distributor and to the injection lances.

The operating principals behind the sorbent injection system are the same as have been used in most other full-scale mercury sorbent injection trials. These injection systems are based upon dilute phase injection, as is this one. The only significant change is that, for the sake of feeding accuracy, gravimetric control will be used instead of volumetric control. The bulk density of PAC based sorbents varies greatly causing the injection rate to vary in volumetrically controlled systems. The gravimetric design of this injection system will overcome this issue.

The layout of the Sorbent Technologies sorbent injection system is shown in Figure 1.

Figure 1. Diagram of the Sorbent Technologies Sorbent Injection System



The day storage hopper, feeder hopper, gravimetric feeder and eductor are all enclosed in a trailer. A bin vent filter is provided to capture any dust generated by material handling. This filter is located on top of the day hopper. Blowers will be used to provide the air flow necessary to convey the sorbent from a tanker to the day storage hopper and to convey the sorbent from the feeder to the injection lances. The first of these blowers is located outside of the trailer. All controls for the operation of the injection system are in an isolated area within the trailer.

The injection system was designed with the ease of installation and disassembly in mind. Only electricity and injection ports are required from the host site to support its operation. Most of the key components are installed in a movable trailer. The injection system was designed to have a sorbent injection rate range from as low as 15 lb/hr to a high of over 600 lb/hr. In this manner, the same injection system can be used at both the Detroit Edison St. Clair Plant and the Duke Power Buck Station.

<u>Mercury S-CEMs</u>

The mercury semi-continuous emission monitors (S-CEMs) have been ordered from project partner PS Analytical. PS Analytical is providing a discount on the equipment so that their new wet/dry mercury conversion modules will be evaluated at the two test sites.

The equipment ordered includes two semi-continuous mercury emission monitors, two wet/dry mercury conversion modules and two inertial sampling probes. The wet/dry mercury conversion modules are the newest innovation in mercury S-CEM monitoring. Prior conversion units were all wet-chemical conversion systems used to either scrub the oxidized mercury from the flue gas or convert it to elemental mercury. These analyzers can themselves only measure elemental mercury.

The new wet/dry system can operate in dry mercury conversion mode, the wet mode, or alternate between the modes. In the dry mode, a thermolytic converter is used to transform the oxidized mercury to elemental mercury when measuring total mercury. The dry conversion systems, when perfected, will provide a leap forward in mercury monitoring technology since two of the most difficult problems of the existing systems, chemicals and their wastes, will be eliminated. These systems should also require less manpower.

PS Analytical will deliver the equipment directly to the Detroit Edison St. Clair Power Plant where project partner Western Kentucky University will provide for the equipment check-out. PS Analytical will also provide the needed training for the operation of the new wet/dry conversion modules. Western Kentucky University has provided the mercury S-CEM operation in many previous projects throughout the utility industry, including the Duke Power Cliffside Plant hot-side ESP qualification trial discussed in Phase III. The mercury sampling and measurement equipment will be used in both the field trials at Detroit Edison and Duke Power.

Sorbent Preparation Equipment

Preparation methods to brominated the sorbents were developed by Sorbent Technologies Corporation in over sevens years of development prior to the project. Detailed operation of the system is proprietary and is covered by pending patents; however, the concept is fairly simple. The Sorbent Technologies sorbents (trademarked B-PAC™) are produced by taking plain powdered activated carbons (PACs) and greatly enhancing their mercury performance through a bromination treatment.

The PAC can be received by either super sack or bulk tanker and the processed B-PAC™ can be shipped in either super sacks or by bulk tanker. This dual material handling capability is necessary to facilitate the smaller quantities of several sorbents that will be required during the parametric testing portions of the program and the larger quantities that will be required of a single sorbent during the long-term tests. The PAC from either the fresh storage silo or a super sack is conveyed mechanically to the bromination reactor. The finished sorbent is conveyed pneumatically either to a product silo before loading into a bulk tanker or into super sacks and into a van trailer for shipment to the test sites.

The sorbent preparation system is designed to minimize any potential release of dust or bromine. The system has both bin vent filters for dust control and a packed column scrubber to control any potential bromine release. A qualified engineering consulting firm has evaluated the sorbent preparation facilities and certified that the potential emissions are *de minimis*.

The delivery of all of the equipment is on schedule to support the Detroit Edison St. Clair Plant program. The exact site in which the equipment will be housed is still pending, however, and this is a point of concern which is discussed further in a later section.

Phase III: Qualification Testing & Support Activities

There are six tasks covered by Phase III. Activities have been conducted to date in two of these tasks and these activities are discussed in this document.

Qualification Testing of Mercury Sorbents for St. Clair

While this project concentrates on brominated sorbents, the particular sorbents and strategies which will be used at Detroit Edison and Duke Power still need to be determined. Smaller-scale qualification testing is designed to finalize the sorbents and strategies selected.

Testing Equipment

Sorbent Technologies Corporation already has a pilot-scale duct-injection pilot plant system for evaluating sorbents in cold-side ESP applications. An EPRI portable test facility sited at a utility boiler burning subbituminous coal was also used to gather data for the cold-side ESP application. Each of these systems is described below.

Pilot-Scale Duct-Injection Testing

Sorbent Technologies Corporation's duct-injection system tests mercury sorbents in the actual in-flight mode. The installed components included a:

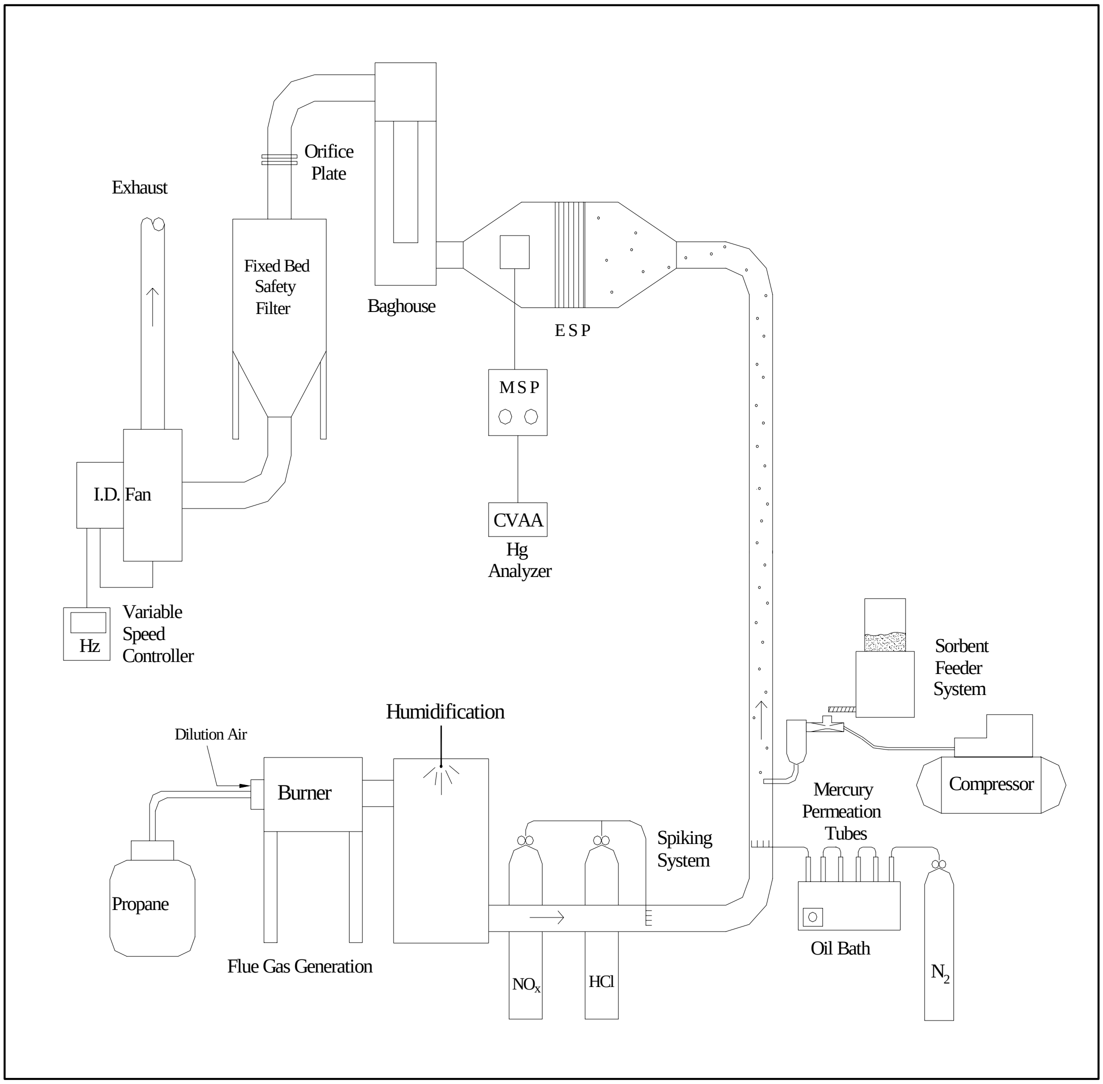
- Humidifier/cooler;
- Insulated pipe "ducting" to provide sorbent residence time and wall contact area;
- Sorbent feeding system to accurately feed at very low rates without agglomeration; and
- Cold-Side ESP (without rapping) to remove any sorbent from the sample stream.

The following operating parameters are typically utilized in the duct-injection system:

° Flow Rate:	55 to 60 acfm
° Sorbent residence time:	2 – 2.5 seconds
° Hg concentration:	22-26 $\mu g/Nm^3$
° SO_2 concentration:	variable up to 1400 ppmv
° NO_X concentration:	variable up to 600 ppmv
° HCl concentration:	variable up to 50 ppmv
° H_2O concentration:	4 wt%, 6.5 vol%
° Temperature at injection point:	330 $\pm$ 10^{O}F
° Temperature at outlet sampling point:	270 $\pm$ 10^{O}F

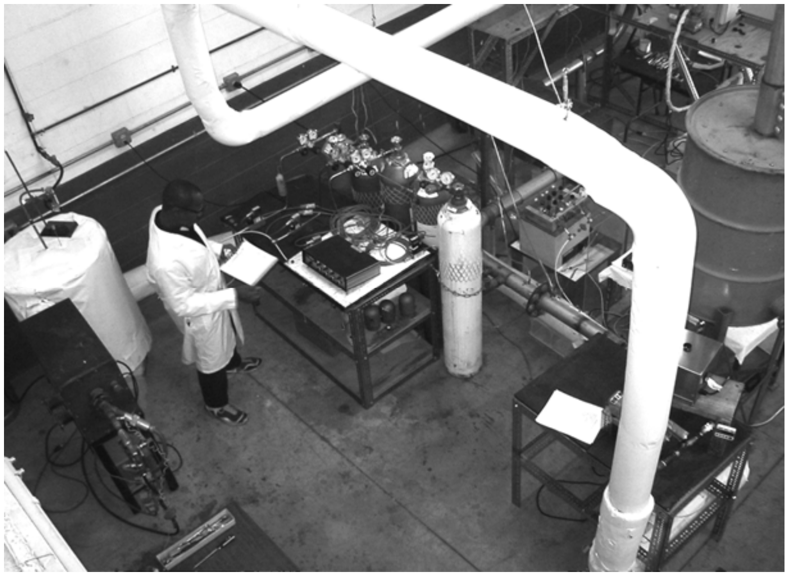
A diagram of the duct-injection system is presented in Figure 2. The system is also shown in Photographs 1 and 2.

Figure 2. Diagram of the Sorbent Technologies Duct-Injection System

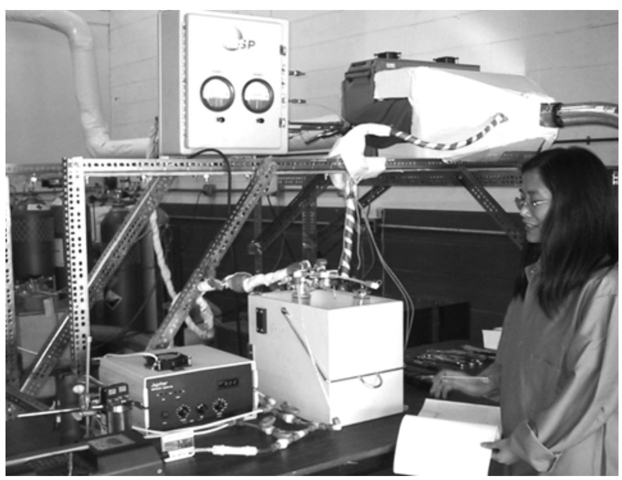


The duct-injection system provides a simulated flue gas comparable to that from a coal fired boiler, with the exception of fly ash. An Ohio Lumex Zeeman-corrected mercury analyzer has been adapted by its manufacturer for use in monitoring the gas-phase mercury concentrations in the system.

Photograph 1. View of the Sorbent Technologies Duct-Injection System

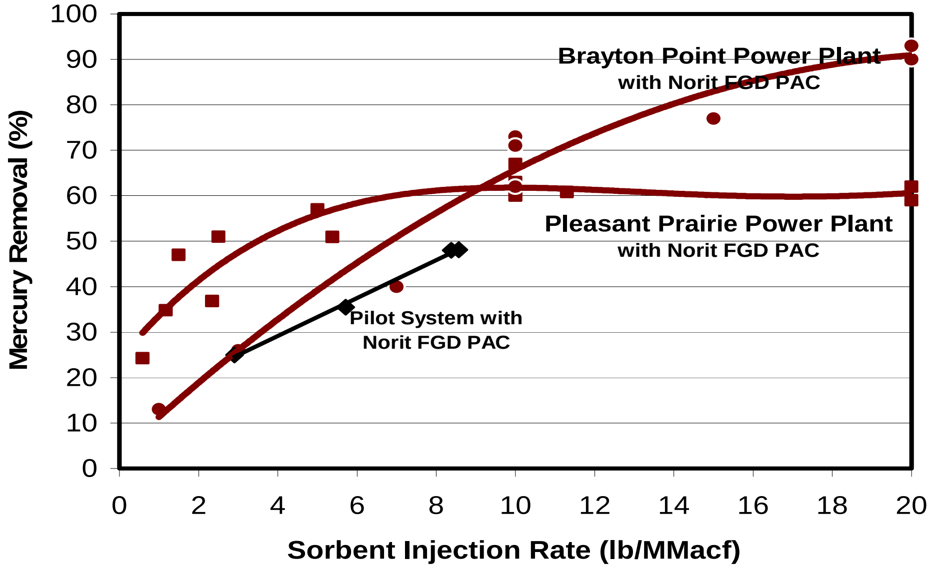


Photograph 2. Analytical Portion of the Sorbent Duct-Injection System
(ESP Top Right)



Norit Darco FGD PAC was tested in the duct-injection system to provide a yardstick for mercury removal comparisons with system to performance to that observed in full-scale field tests. The mercury removal results for the Norit Darco FGD PAC in the duct-injection system are presented in Figure 3.

Figure 3. Pilot Duct-Injection System Hg Removal Results Plotted with the Results from Brayton Point and Pleasant Prairie



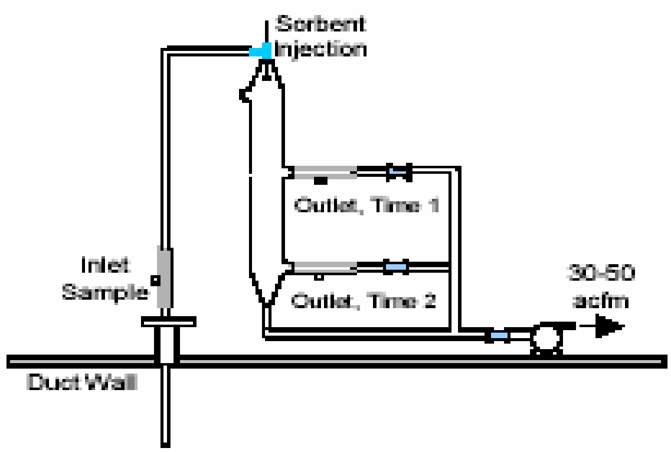
The mercury removal results using the same plain PAC sorbent that was used in the earlier Brayton Point and Pleasant Prairie full-scale tests are presented in Figure 3 for comparison purposes. The mercury removal results from the duct-injection system are slightly below those achieved in the two full-scale tests. It is believed that the difference is due, in large part, to the added mercury removal that comes from the build-up of sorbent deposits as full-scale tests continue. These deposits have been found to provide as much as 10% extra mercury removal. The Sorbent Technologies duct-injection system is not operated long enough to allow for the build-up of deposits and any sorbent remaining after a run is either removed or saturated with mercury so that it will not have any impact on the next test. Still, the duct-injection system does provide results comparable to full-scale tests. In this program, the duct-injection system will be used in a series of sorbent qualification tests to identify the sorbents for the full-scale trials. It will also be used to confirm the quality of sorbents prepared in the sorbent preparation system.

Slipstream Qualification Testing with EPRI's PoCT System

The Detroit Edison St. Clair Plant typically burns a coal blend that is predominately subbituminous coal. An opportunity arose to test some of the potential sorbents for the project's long-term Detroit Edison St. Clair Power Plant trial in a small slipstream sorbent-injection system which used the flue gas from a boiler burning subbituminous coal.

The "Pollution Control Test" (PoCT) system is owned by the Electric Power Research Institute and operated by Apogee Scientific, Inc. It was temporarily installed at the We Energies' Pleasant Prairie Plant, where the first DOE full-scale duct-injection trials were held. In these previous full-scale trials, a mercury-removal plateau appeared and no amount of activated carbon injection could appear to penetrate it. In the PoCT slipstream tests, the plant flue gas was drawn off after the ESP, so the gas did not contain fly ash, but the tests could confirm the more extensive tests on Sorbent Technologies pilot duct-injection system, which only used a simulated subbituminous flue gas. A diagram of the system is presented in Figure 4.

Figure 4. The EPRI/Apogee PoCT System Used at We Energies' Pleasant Prairie Power Plant

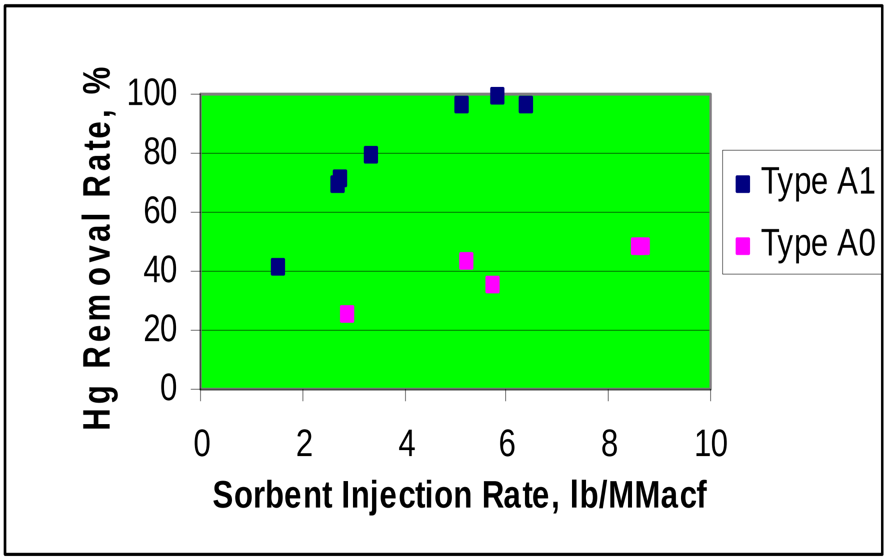


The in-flight module system is very simple in design. Flue gas is drawn from a duct after it has passed through the plant cold-side ESP. The flow rate of the flue gas through the pilot system is between 30-50 acfm. Sorbent is injected at the entrance to an open chamber. For these tests, the injection temperature was always about 300^{O}F. The mercury concentration in the flue gas is measured at three locations. The first is the inlet to the simulated duct before the sorbent injection location, the second and third locations are situated downstream at intervals, in this case, corresponding to in-flight residence times of 1.6 or 3.6 seconds. A mercury cold vapor atomic absorption spectrometer is used for all of the mercury measurements.

Results and Discussion

The Sorbent Technologies' B-PAC brominated mercury sorbents are powdered activated carbons that have been brominated. The sorbent results below for the laboratory pilot system are for types A1, A3, A5, and A15, with the various designations indicating different combinations of base carbon, degrees of bromination, or manufacturing variations. Plain Norit Darco FGD PAC is referred to here as Type A0. The duct-injection mercury removal results for the Type A0 and A1 sorbents are indicated in Figure 5.

Figure 5. Sorbent Technologies Duct-Injection System Tests with Sorbents A0 and A1

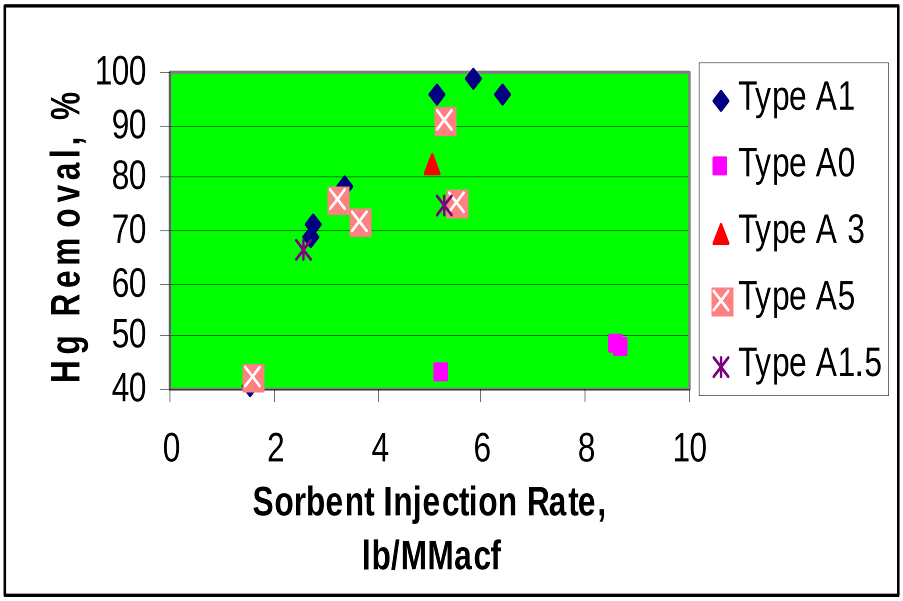


In the duct-injection pilot system, the Type A1 sorbent significantly outperformed the A0 sorbent, achieving about 70% Hg removal versus 25% Hg removal at an injection rate of 3 lb/MMacf. The Type A1 sorbent achieved 80% mercury removal at an injection rate of 3.4 lb/MMacf and 94% Hg removal at an injection rate of 5.8 lb/MMacf. The A0 sorbent never achieved even 50% Hg removal at an injection rate near 9 lb/MMacf.

There are two points together at about 70% Hg removal and an injection rate of 3 lb/MMacf. These are duplicate runs performed three months apart, indicting the reproducibility of the test method.

The pilot duct-injection results for all of the sorbents discussed in this section are presented in Figure 6.

Figure 6. Sorbent Technologies Duct-Injection System Tests with Sorbents A0, A1, A3, A5, and A15



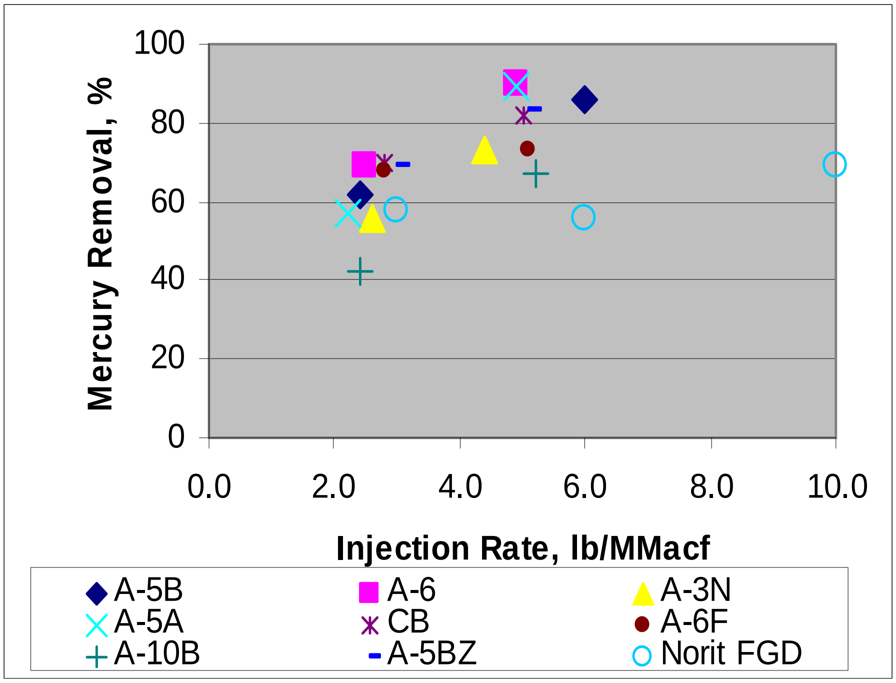
Not all of the various Type A sorbents provided the same degree of mercury removal. Some performed better than others. The search for the most cost-effective combination of production variables for brominated carbon sorbent will continue. The sorbents to be used at St. Clair will be the least expensive version of B-PAC likely to provide high mercury removal rates. It is likely that different sorbent combinations will ultimately be called for in different power plant applications. Consequently, several B-PAC sorbents will be evaluated in the parametric portion of the trials at the Detroit Edison St. Clair Power Plant.

<u>Slipstream Qualification Testing with EPRI's PoCT System</u>

The opportunity arose to have a subcontractor, Apogee Scientific, test a number of B-PAC variations on a slipstream of actual subbituminous-coal flue gas at the We Energies Pleasant Prairie Plant, which hosted the first full-scale DOE activated carbon injection trials.

A total of nine sorbents were tested in the pilot tests at the We Energies' Pleasant Prairie Plant. Seven of the nine sorbents were manufactured by Sorbent Technologies Corporation (STC) while the other two were commercial materials. The STC sorbents tested were denoted A -5B (currently the STC standard), A-6 (a first-generation concrete-friendly sorbent), A-3N, variants of A-5 called A-5A and A-5BZ, and a variant of A-6 (A-6F). One of the commercial materials was Norit Darco FGD, for a yardstick, and the other sorbent was an iodinated activated carbon from Calgon named CB, which is commercially available in small quantities.

Figure 7. Mercury Removal Results from Pleasant Prairie Slipstream Tests



In the PoCT testing, all of the brominated sorbents performed better than Norit Darco FGD. The A-6 "concrete-friendly" sorbent achieved 90% mercury removal in the 3.6 second residence time at an injection rate of 4.9 lb/MMacf, while the A-5B sorbent achieved 86% mercury removal at an injection rate of 6.0 lb/MMacf. The Norit Darco FGD sorbent could only achieve a mercury removal rate of 56% at an injection rate of 6.0 lb/MMacf. Even at the high injection rate of 10 lb/MMacf, this plain carbon could only capture 69% of the mercury. The iodinated Calgon CB PAC did better, but was still not as good as the A-6 or A-5B sorbents. The A-3N, A-5BZ, and A-10B sorbents did not perform quite as well as the A-5B or A-6 versions, but still did better than did the plain Norit Darco FGD PAC. The numeric results from the testing at Pleasant Prairie are presented in Table 1.

Table 1. Results from Slipstream Tests at Pleasant Prairie

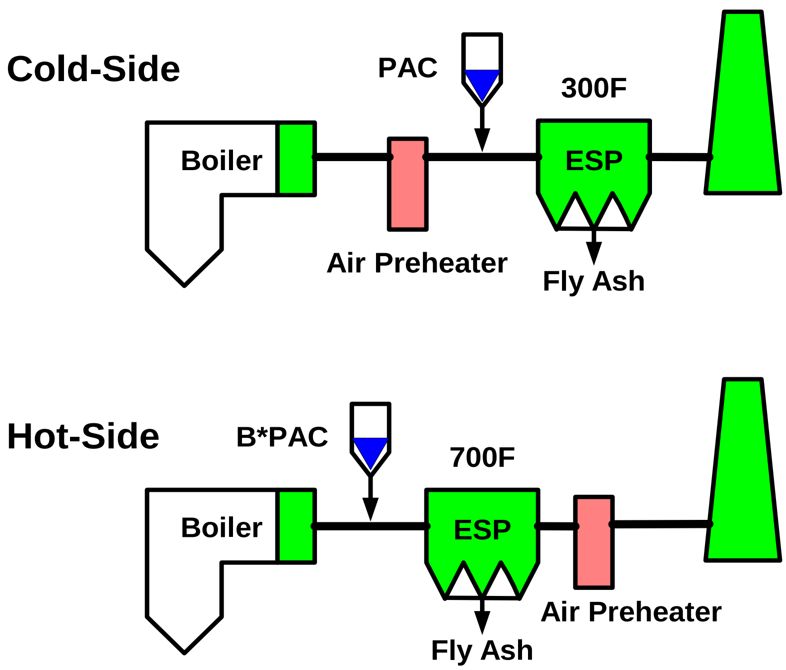
Sorbent	Injection Rate, lb/MMacf	Mercury Removal, %
A-1	2.4	42
A-1	5.2	67
A-3N	2.6	56
A-3N	4.4	73
A-5A	2.2	57
A-5A	4.9	89
A-5B	2.4	62
A-5B	6.0	86
A-5BZ	3.0	69
A-5BZ	5.1	83
A-6	2.5	69
A-6	4.9	90
A-6F	2.8	68
A-6F	5.1	73
Calgon Iodinated CB	2.8	70
Calgon Iodinated CB	5.0	82
Norit Darco FGD	3.0	58
Norit Darco FGD	6.0	56
Norit Darco FGD	10.0	69

Qualification Test on a Hot-Side ESP

Background

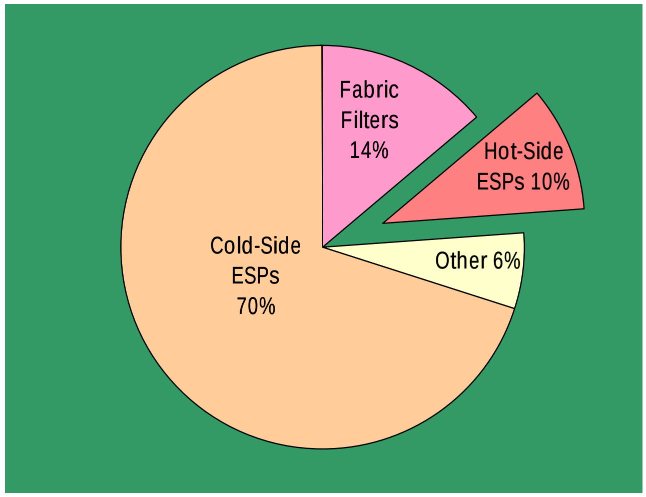
Hot-side electrostatic precipitators (ESPs) operate in a much higher temperature range (500 - 800^{O}F) than do cold-side ESPs (250 - 400^{O}F). At these higher temperatures the resistivity of some fly ashes allows them to be effectively captured electrostatically. A hot-side ESP must treat a larger volume of gas than does a cold-side ESP, however, because of its elevated temperature.

Figure 8. Cold-Side ESPs versus Hot-Side ESPs



Structurally, the only change is in the placement of the air preheater, as is shown in Figure 8. The air preheater is located before the ESP in a cold-side design, but after the ESP in a hot-side ESP. As is shown in Figure 9, about 10% of the more than 1000 boilers in the United States are equipped with hot-side ESPs.

Figure 9. Distribution of Particulate Control Equipment at U.S. Coal-Fired Boilers



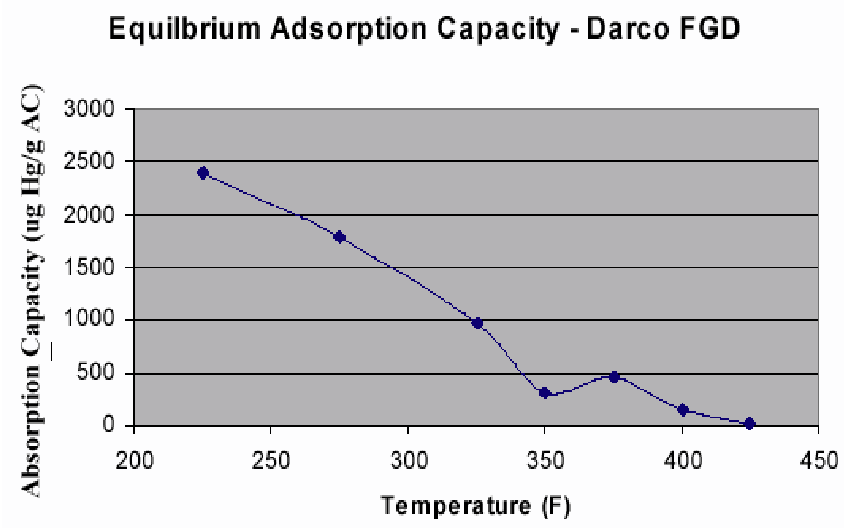
As part of the EPA's 1999 Information Collection request testing, mercury measurements were made at 14 boilers equipped with hot-side ESPs. The average mercury emission levels at these plants, both at the inlet to the ESP and at the outlet, are provided in Table 2.

Table 2. Hot-Side ESP Mercury Emissions (ICR Data)

Coal	Particulate Control	Sampling Location	Mercury (ug/Nm3) (p)	(+2)	(0)
Bituminous	HS ESP Only	Inlet	0.7	3.7	2.8
(Avg. of 4 boilers)		Outlet	0.3	3.7	2.5
Subbituminous	HS ESP Only	Inlet	0.1	2.3	10.7
(Avg. of 4 boilers)		Outlet	0.1	2.3	9.2
Bituminous	HS ESP/Scrubber	Inlet	0.0	8.7	3.9
(1 boiler)		Outlet	0.0	1.7	4.9
Subbituminous	HS ESP/Scrubber	Inlet	0.5	2.2	3.0
(Avg. of 5 boilers)		Outlet	0.1	0.5	3.5

The boilers equipped with hot-side ESPs have essentially no native removal of mercury. The unburned carbon in their fly ashes apparently does not adsorb mercury at the elevated temperatures. The boilers with scrubbers do collect a significant portion of the oxidized mercury that passes through the hot-side ESP, but it appears that some is converted to elemental mercury and re-emitted.

Figure 10.



Controlled laboratory tests by others (Durham, 2003) have indicated that typical activated carbon does not have any mercury capacity at the elevated hot-side ESP temperatures. See Figure 10. Thus, prior to these tests, the options for mercury control in boilers equipped with a hot-side ESP appeared limited to injection into a newly-installed cold-side ESP or baghouse after the air preheater, conversion to a cold-side ESP, or unit retirement. All of these options would be very expensive.

Earlier laboratory testing indicated that B-PAC^{TM} sorbents maintained their mercury removal ability at elevated temperatures, as shown in Figure 11. These results were confirmed by subsequent testing performed by URS Corporation in their high-temperature laboratory fixed-bed system, operated at 650^{O}F, as shown in Figure 12.

Figure 11. B-PAC^{TM} Sorbent Mercury Removal vs. Temperature

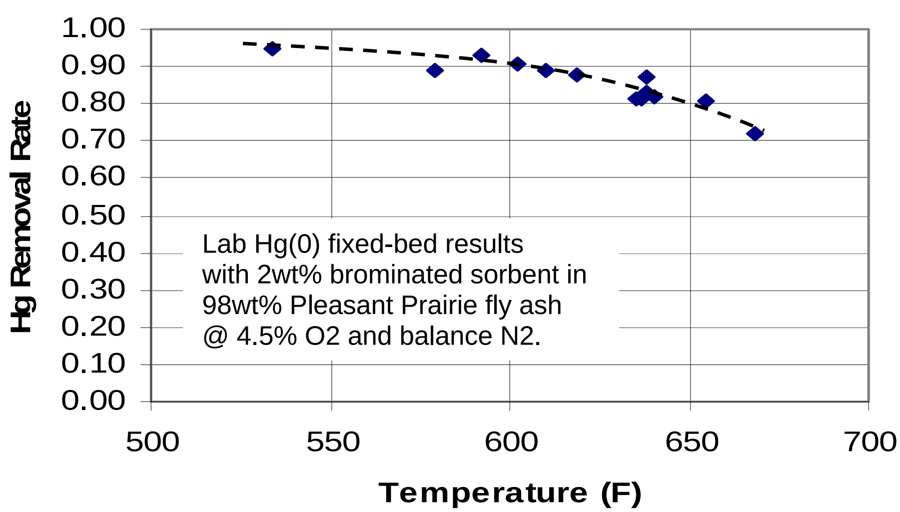
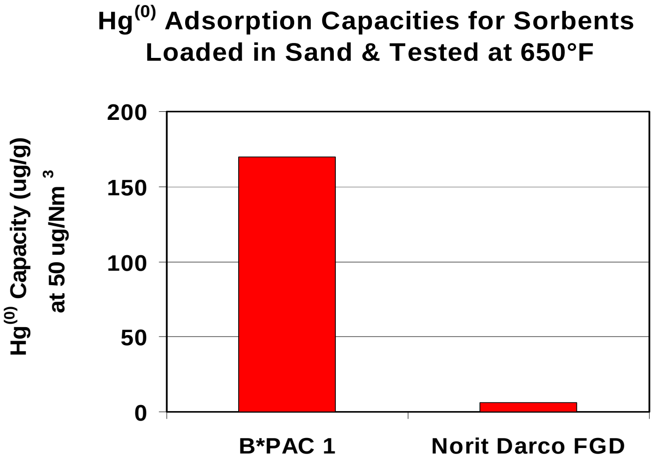


Figure 12. High Temperature URS Fixed-Bed Mercury Test Results



These results provided hope that sorbents could be used directly to capture mercury in hot-side ESPs, a much lower cost option for these facilities. However, the project participants wanted to perform short hot-side ESP qualification tests before committing to a larger, long-term trial at the Buck Station. These consisted of short parametric injection tests using the B-PAC™ sorbents on the smallest hot-side ESP in Duke's system. Norit Darco FGD PAC was also tested since it has been the baseline sorbent for all previous mercury sorbent field tests.

Test Plan

Boiler No.2 at the Duke Power Cliffside Plant was selected for the hot-side ESP qualification test. This boiler has a capacity of 40 MWe. The boiler is tangentially fired and uses low-sulfur Eastern bituminous coal. The coal contains approximately 0.08 ppm of mercury and 500 ppm of chlorine. The typical mercury content of the flue gas is 5-10 $\mu g/Nm^3$ of which most is in the oxidized form. The hot-side ESP is very small with an SCA of only 240 ft^2/Kacfm from two fields. The plant is shown in Photograph 3.

Photograph 3. Duke Power's Cliffside Plant

Boiler No.2 is the second one from the rear. Boiler No.2 is a peaking boiler which normally only operates at full load during the daylight hours on weekdays during high electric usage months and usually not at all on weekends. It was constructed in 1939 and refurbished in the 1980s.

The test plan for the hot-side ESP qualification test at the Cliffside Plant is presented in Table 3.

Table 3. Duke Power Cliffside Plant Hot-Side ESP Hg Sorbent Trial Plan

	Friday 9/12/03		Saturday 9/13/03		Sunday 9/14/03	
	Day 1		Day 2		Day 3	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
		3:00				
Activities	Travel	Safety Meeting	Equipment Assembly		Equipment Check-out	

	Monday 9/15/03		Tuesday 9/16/03		Wednesday 9/17/03		Thursday 9/18/03		Friday 9/19/03	
	Day 4		Day 5		Day 6		Day 7		Day 8	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
Sorbent		None	A-5	A-5	A-1	A-11	A-1	A-1	A-1	A-1
OHM Testing		Yes		Yes		Yes	Yes		Yes	
Activities	S-CEM begins	Baseline Testing	Sorbent Injection	Sorbent Injection	Sorbent Injection	Sorbent Injection	Sorbent Injection	Sorbent Injection	Sorbent Injection	Sorbent Injection
	Test Equipment						Varying Load 11-40 MWe			

	Saturday 9/20/03		Sunday 9/21/03		Monday 9/22/03		Tuesday 9/23/03		Wednesday 9/24/03	
	Day 9		Day 10		Day11		Day 12		Day 13	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
Sorbent					A-6	A-6	A-5F	A-12		
Sorbent							A-6	A-0		
Activities	Boiler Down Equipment Repair and Calibration		Boiler Down Equipment Repair and Calibration		Sorbent Injection	Sorbent Injection	Sorbent Injection	Sorbent Injection	Equipment Disassembly	Travel

The plan called for arriving at the plant on Friday September 12, 2003 to attend a safety orientation meeting. All of the mercury monitoring equipment and the sorbent injection equipment was assembled and checked out over the next two days. Monday was a baseline testing day during which the mercury S-CEM operation was initiated and a series of OHM tests performed. The injection trials began the next day and ran through Friday. A series of OHM tests were made on each of these days. The mercury S-CEM operation continued throughout the week. On the weekend, all of the equipment was inspected, repaired if necessary, and recalibrated. The injection trials resumed on Monday September 22 and ran for two more days. The Hg S-CEM was in operation during these days, but no OHM tests were run. The equipment was disassembled on Wednesday September 24th and the test crews departed.

A total of seven different sorbents were evaluated during the Cliffside tests, including the Norit Darco FGD PAC yardstick sorbent. The other sorbents were prepared by Sorbent Technologies in their facilities in Twinsburg, Ohio.

Equipment Used

<u>Mercury Measurement Equipment</u>

Mercury measurements were made upstream of the ESP and sorbent injection location and downstream from the ESP at the stack. New ports were provided in the ductwork leading to the ESP to facilitate the Ontario Hydro Method (OHM) equipment. The testing in the stack used existing ports. Four OHM Hg trains were run simultaneously; two in the inlet duct and two at the stack. In this manner, duplicate analyses were provided. The OHM testing was performed on five different days during the test program by Trigon Engineering Consultants of Charlotte, North Carolina. The OHM inlet sampling equipment used in the ESP inlet ductwork is shown in Photograph 4.

Photograph 4. Ontario Hydro Method Hg Testing in the Cliffside ESP Inlet Duct
Photograph 5. W. Kentucky Univ. Personnel with Hg Conversion Modules and Analyzer

An additional port, in the same line with but above the ports used for the inlet OHM tests, was installed in the inlet ductwork to facilitate the S-CEM Hg monitoring. An existing port in the stack was used for the outlet testing. The flue gas was separated from the particulate matter by means of inertial separators from Apogee Scientific at both sampling locations. The flue gas was passed through heated lines to two mercury conversion modules, one for each sampling location. The gas from the conversion modules was directed to a PS Analytical Sir Galahad mercury analyzer. The analyzer coupled with the conversion modules could provide both elemental and total vapor phase mercury analyses. The system was arranged to measure only total vapor phase mercury analyses during most of the trial since the elemental mercury content of the flue gas was minimal and this provided more frequent points for total Hg. The S-CEMs were provided and operated by Western Kentucky University (Photograph 5).

Sorbent Injection Equipment

The sorbent injection equipment was brought to the Cliffside plant in pieces and assembled on site. The new injection trailer, when it is available, will avoid this field testing problem. The injection system used in this project was similar to that used in most of the field trials to date. It was based upon dilute phase conveying of the sorbent.

The sorbent was stored in a hopper connected to a volumetric feeder. The feeder was calibrated for mass flow before and after each test. Sorbent from the feeder was directed through an eductor to the dilute phase conveying system. A compressor was used to provide the conveying air. The injection stream was split into three streams before being conveyed by flexible hose to three lances for injection into the ductwork upstream of the ESP. The injection system and sorbent distributor are shown below in Photographs 5 and 6.

Photograph 5. Sorbent Injection Hopper and Screw Feeder at Cliffside

Photograph 6. Sorbent Injection Stream Splitter at Cliffside

Results and Discussion

Mercury Removal Performance

The various operating conditions tested in the Cliffside trials are shown in Table 3. When the boiler operated at 40 MWe, the temperature at the injection location ranged between 655°F and 686°F. The boiler also routinely operated at different loads down to about 12 MWe, though lower-load operation was only tested one day. The flue gas flow rates at the injection location were difficult to measure accurately due to highly-skewed gas flow in the duct. As a result, the flow data from the stack was corrected for temperature and oxygen content to calculate the flue gas flow rates shown. The flow rate at the injection location was about 300,000 acfm under maximum load and about 75,000 acfm at minimum load.

During these short-term tests, the sorbents were injected at rates of from 1.8 to 11.2 lb/MMacf under a variety of operating conditions. The average duration of a test was about two hours.

The mercury removal was evaluated using three methods. The data from the mercury S-CEM was used to make one of these calculations. The high-temperature inlet sampling system had problems throughout the test program, so only data from the stack outlet S-CEM was utilized for evaluating performance. The mercury concentrations at the stack before and during sorbent injection were compared to provide the mercury removal value by this method.

An example of the Hg S-CEM data, this for Wednesday September 17th, is shown in Figure 13. A series of injection trials was conducted on that day. The impact of sorbent injection is readily apparent. As soon as injection begins, the mercury level at the stack dropped. The mercury level plateaus soon after injection begins. Immediately after the injection process is terminated, the mercury level jumped back to near baseline levels.

Figure 13. Cliffside S-CEM Hg Total Outlet Data on 9/17/03

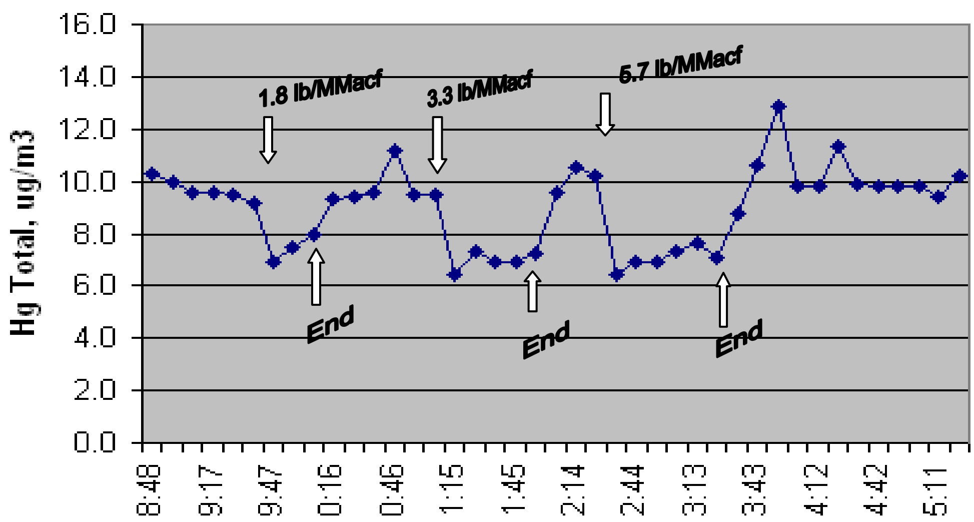


Table 3. Duke Power Cliffside Plant Test Conditions

Date	Sorbent	Injection Rate, lb/MMacf	Power Rate MW	Injection Temp., F	Flue Gas Flow Rate, acfm
9/15/03	None	NA	40	*655*	294,000
9/16/03	A-5	3.3	40	*686*	304,000
9/16/03	A-5	7.1	40	*686*	304,000
9/17/03	A-1	1.8	40	*686*	299,000
9/17/03	A-1	3.3	40	*686*	299,000
9/17/03	A-1	5.7	40	*686*	299,000
9/17/03	A-11	4.1	40	*686*	299,000
9/18/03	A-1	6.2	12	*530*	77,000
9/18/03	A-1	4.9	20	*572*	129,000
9/18/03	A-1	3.8	30	640	237,000
9/19/03	A-1	Ramp 0 to 10.3	40	*676*	324,000
9/19/03	A-1	3.8	40	*676*	324,000
9/22/03	A-6	4.9	40	665	305,000
9/22/03	A-6	4.0	40	665	305,000
9/22/03	A-6	5.6	40	665	305,000
9/23/03	A-6	5.1	40	662	305,000
9/23/03	A-5F	3.9	40	662	305,000
9/23/03	A-12	3.9	40	662	305,000
9/23/03	Darco FGD	3.6 to 11.2	40	662	305,000

The second method of calculating mercury removal was by the use of the OHM test data. The inlet and outlet OHM mercury concentrations, corrected for oxygen, were compared to calculate the mercury removal from this data. Except for the baseline testing, the injection operation was started well before an OHM test began and stopped only after the OHM test was concluded.

The third method of calculating mercury removal was through the use of fly ash mercury concentration data. For the first four days of the project, manpower was available to perform the difficult task of fly ash sampling from the ESP hoppers. This effort is difficult in any boiler, but it is even more so at the elevated temperatures of a hot-side ESP. Obtaining samples only representing the period of the test is also difficult. Samples were taken from all hoppers and a composite was made to represent the front and back fields. The fly ash samples were split and analyzed for mercury by both Sorbent Technologies Corporation and by Trigon Engineering Consultants. The results are presented in Table 5. (Note that as there may not be plug flow of sorbent through the system, representative amounts of sorbent and captured mercury may not be found in the fly ash samples collected in short-term tests such as these.)

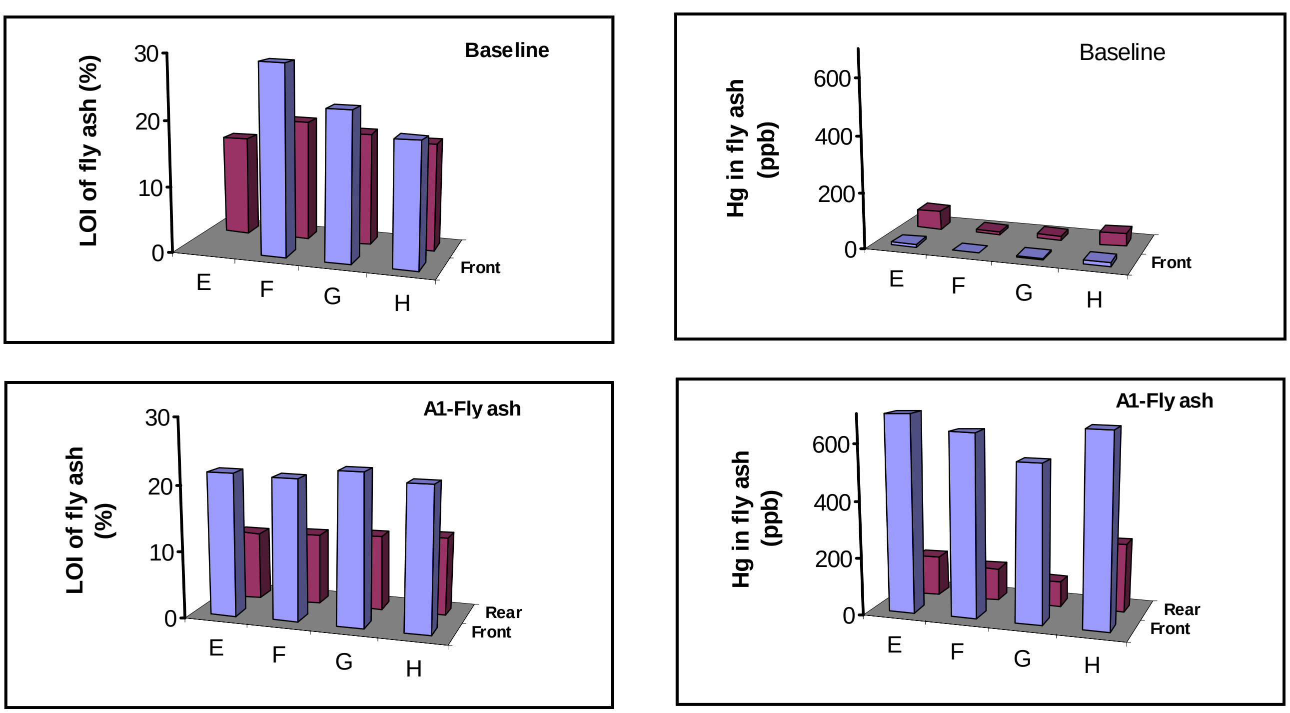
Table 5. Duke Power Cliffside Fly Ash Mercury Analyses

Date	Condition	Location	STC Hg, ppb	Trigon Hg, ppb
9/15/03	Baseline Test	Front Field	6	17
9/15/03	Baseline Test	Back Field	35	39
9/16/03	A-5 Injection	Front Field	110	98
9/16/03	A-5 Injection	Back Field	233	193
9/17/03	A-11 Injection	Front Field	63	50
9/17/03	A-11 Injection	Back Field	119	86
9/18/03	A-1 Injection	Front Field	642	596
9/18/03	A-1 Injection	Back Field	148	131

The fly ash mercury concentrations measured by the two different companies using different measurement methods compared favorably. There was very little mercury in the fly ash during the baseline day with the amount increasing for the first two days of injection and jumping higher for the first test on 9/18/03. A simple mercury mass balance was made using the coal mercury level and the coal flow in order to calculate a mercury removal rate with this data.

Below is fly ash data comparing the LOI and mercury from each of the four hoppers from each of the two ESP fields with no injection (baseline) and B-PAC injection at low load. Cliffside has high unburned carbon, but this gets out almost no mercury. The fly ash incorporating sorbent, however, had high Hg concentrations. Little sorbent appeared to make it through the first field.

Figure 14. Fly Ash Compositions With, and Without, Sorbent



The mercury removal rates as calculated by the three means of measurement are presented in Table 6.

The baseline period was evaluated by all three methods of calculating mercury removal. The methods based upon the fly ash and S-CEM data both indicated that there was little native removal of mercury. Native mercury removal is that observed without the injection of sorbent. The OHM data indicated that there was 24%. This is highly unlikely since there was very little mercury detected in the fly ash (see Table 5 and Figure 14).

Table 6. Duke Power Cliffside Mercury Testing Results

		Injection Rate,	Power Rate		Sorbent Hg Removal	
Date		lb/MMacf	MW	S-CEM, %	OHM, %	Fly Ash, %
9/15/03	None	NA	40	-9	24	2
9/16/03	A-5	3.3	40	NA		
9/16/03	A-5	7.1	40	6	0	13
9/17/03	A-1	1.8	40	16		
9/17/03	A-1	3.3	40	28		
9/17/03	A-1	5.7	40	31		
9/17/03	A-11	4.1	40	15	69	7
9/18/03	A-1	6.2	12	78	77	80
9/18/03	A-1	4.9	20	49		
9/18/03	A-1	3.8	30	42		
		Ramp				
9/19/03	A-1	0 to 10.3	40	35	87	
9/19/03	A-1	3.8	40	39		
9/22/03	A-6	4.9	40	29		
9/22/03	A-6	4.0	40	27		
9/22/03	A-6	5.6	40	24		
9/23/03	A-6	5.1	40	19		
9/23/03	A-5F	3.9	40	27		
9/23/03	A-12	3.9	40	22		
9/23/03	A-0	3.6 to 11.2	40	0		

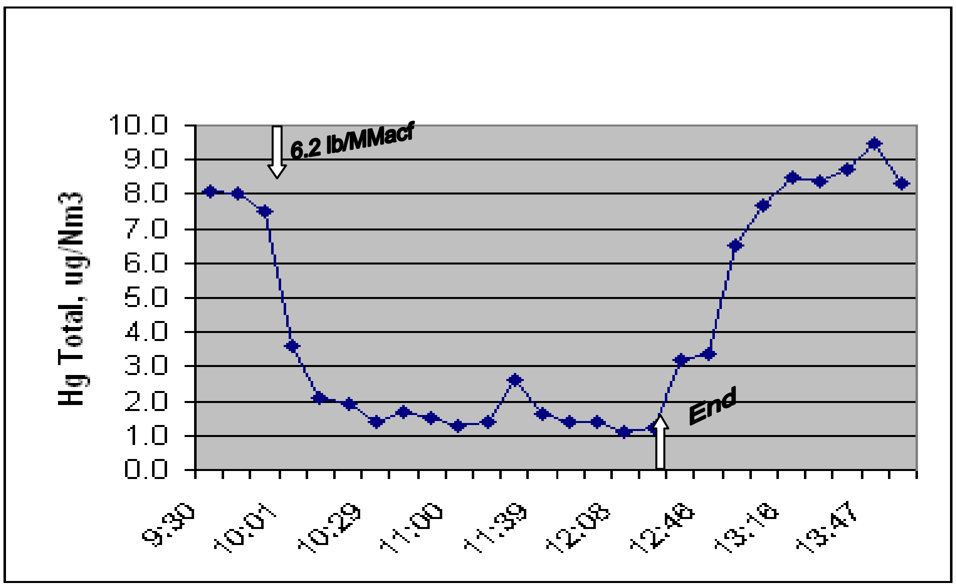
Mercury removal was calculated for every run using the Hg S-CEM data. At maximum load, a mercury removal rate of up to about 40% was observed. This mercury removal rate increased as the boiler load was reduced up to about 80%. There were only four tests in which the mercury removal rate could be determined by all three methods. One was the baseline test as previously discussed. The other three were from injection tests. The results agree fairly well for two of the three tests. All the data for the test on 9/13/03 indicates that a low mercury removal rate was achieved while all the data for the test on 9/18/03 indicates that a high mercury removal rate was achieved. The OHM data for the test on 9/17/03 indicates that a high mercury removal rate was achieved, while the S-CEM data and the fly ash data indicate that a low mercury removal rate was achieved.

There was one day when both S-CEM and OHM data were available. On this day, the S-CEM data indicated a moderate mercury removal level while the OHM data indicated a high mercury removal level. Unfortunately, there was no fly ash data for this day. In some test programs, only OHM and S-CEM mercury testing is performed. In that situation, any discrepancy in the two readings is hard to resolve. A third measure of mercury measurement is needed. Fly ash mercury analyses can supply this needed information if a representative sample can be obtained. The fly ash mercury data provides a high degree of confidence that the OHM data was in error on the baseline day of 9/15 and, to a lesser degree, on the testing days of 9/17 and probably 9/19. The mercury S-CEM and fly ash data always compared very well.

There are several potential reasons that the OHM data could be incorrect. First, the OHM test was not designed for high temperature applications such as at the Cliffside Plant. Second, there was no location in the ductwork before ESP in which all of the standard sampling criteria could be met. In fact, the flow was very biased in the area of sampling, but it was the only inlet location available. Finally, the samplers used an external filter in a heated box through which to draw the flue gas. This box was many hundreds of degrees below the flue gas temperature and certainly biased their particulate mercury measurements, if not all of their inlet mercury data. In future testing, a filter in the ductwork will be used to avoid the latter problem.

The Hg S-CEM data for the injection trial conducted at low load is presented in Figure 9.

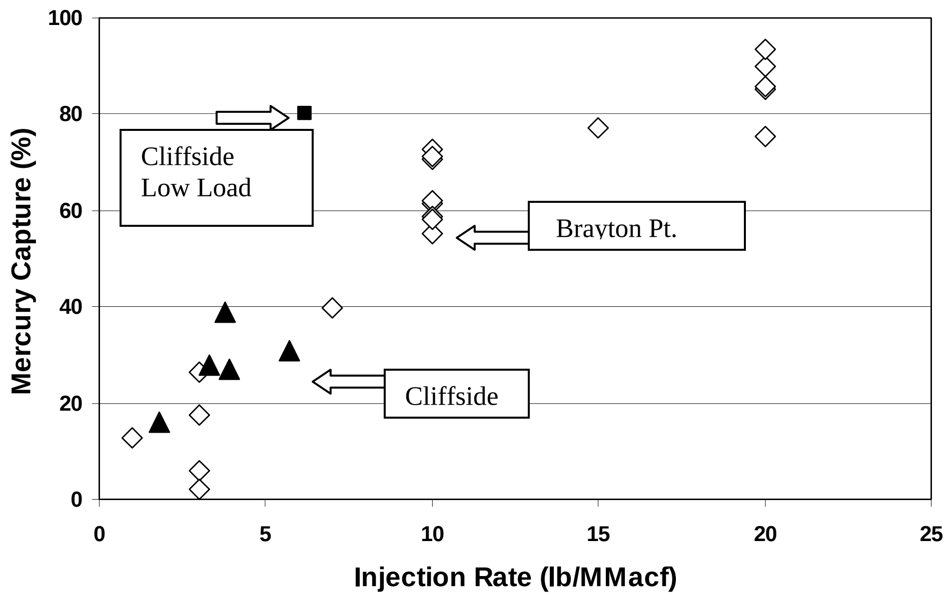
Figure 15. Cliffside Hg S-CEM Curve for Low Load Trial on 9/18/03



The B-PAC™ sorbent in this case performed much like it would in a cold-side application, achieving about 80% mercury removal. The plain PAC (Norit Darco FGD) gave no evidence of any mercury removal at all, as expected. The B-PAC™ sorbents provided fairly good results under the challenging plant conditions.

The mercury removal results for the standard A-5 B-PAC sorbent are shown in Figure 16. The data is presented on the same curve as the data from the Brayton Point full-scale demonstration test using plain Norit Darco FGD sorbent. This facility also used a low-sulfur bituminous coal, but was equipped with a cold-side ESP. The data from the Cliffside test for the hot-side application falls on the same curve as that for Brayton Point for the cold-side application.

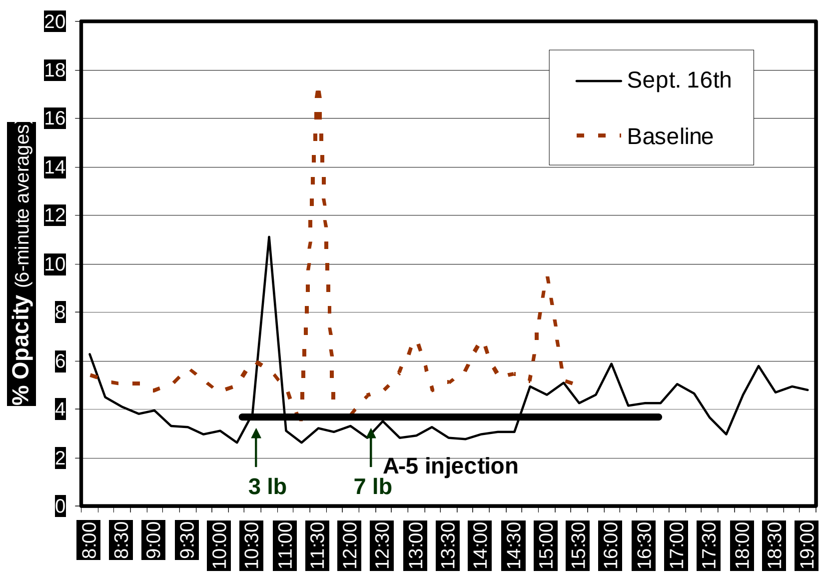
Figure 16. Mercury Capture vs. Injection Rate at Cliffside and Brayton Pt.



Balance-of-Plant Effects

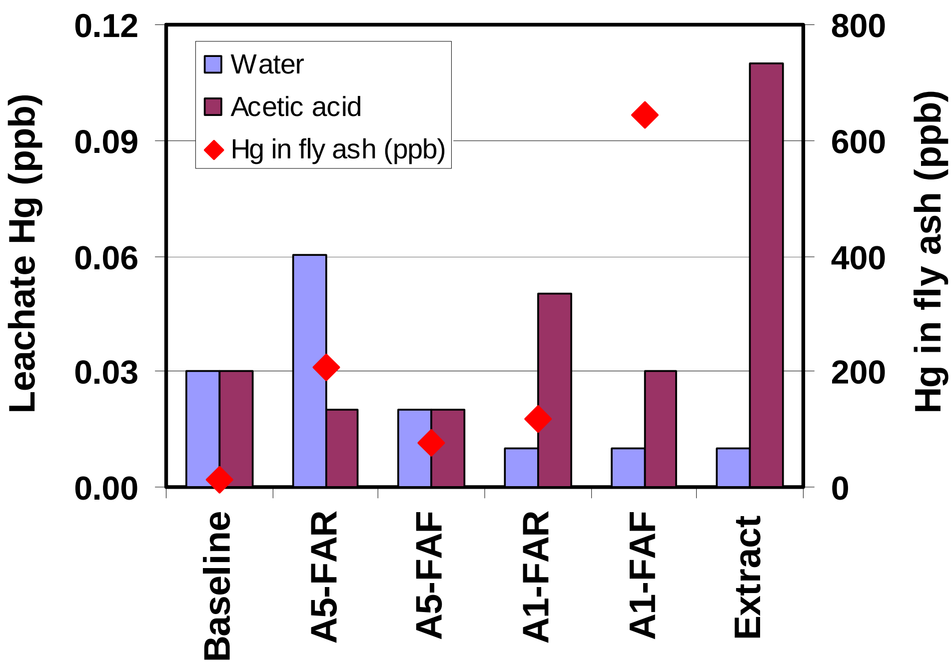
Operations of the plant systems were closely monitored during the tests to detect any balance-of-plant effects. Of particular interest were possible impacts of sorbent injection on stack opacity and ESP operation. Sorbent injection added about 2 or 3wt% to the particulate load. Except for when the injection air was turned on for the first time, blowing accumulated fly ash off the turning vanes directly in front of the lances, there was no measurable impact upon ESP performance during the injection trials. Plant opacity for the baseline day and first day of injection, for example, are presented in Figure 11.

Figure 17. Duke Power Cliffside Boiler No. 2 Opacity on Two Days



Another possible concern is that the mercury captured in the sorbent in the fly ash could be leached into the environment. Previous tests have shown that the mercury captured by carbon sorbents is very difficult to remove from the sorbent. This has been found to be especially true with the B-PAC™ sorbents. The fly ash sample containing the highest level of mercury in the Cliffside runs, 620 ppb, was subjected to the Toxic Characterization Leaching Procedure (TCLP) with acetic acid and distilled water. The resulting mercury concentrations in the leachates were very low, particularly after correcting for the mercury in the extraction solution blanks. See below. The baseline ash did not contain sorbent, while the fly ash (FA) samples came from either the Front [F] or Rear [R] field hoppers.

Figure 18. Toxic Characteristic Leaching Procedure & Water Leachates of Cliffside Ashes



A sample of the sluice water was also taken at the same time as this fly ash sample and it contained less than 0.005 µg/L of mercury. Mercury leaching at Cliffside did not appear to be a problem.

Based upon the positive results of the Cliffside test, the project sponsors supported proceeding with the project's 30-day full-scale trial at the larger Buck Power Plant, which also uses a hot-side ESP for particulate control.

Conclusions and Accomplishments

In very short-term, small but full-scale testing, Sorbent Technologies' B-PAC™ brominated carbon sorbents have exhibited a potential to provide mercury capture at the high temperatures present in hot-side ESPs. Longer term tests, such as that at Duke's Buck Plant later in the project, are needed to fully demonstrate the potential of these sorbents.

Problems Encountered

The only major problem encountered to date relates to the location for the sorbent preparation system. Originally, it was planned to have the system housed in another unit of the same complex Sorbent Technologies offices and laboratories. This is a heavily industrialized area in which the facility was a good fit. However, the potential site never became available.

A search for other potential sites discovered a toll processor not too distant from the Sorbent Technologies location that would not only lease the space for the sorbent preparation system but also lease the employees needed to operate the system on an as-needed basis. Negotiations were proceeding well when the head of this organization informed Sorbent Technologies that they could not guarantee that they would be in operation for the duration of the DOE project. It was decided that we could not take the risk of the toll processor closing during the project, despite the advantages this arrangement would have had.

This event put us back at the beginning of the site search process. A large number of potential sites were examined, with most being discarded as not practical. In the meantime, we were informed that the original site in the same building as Sorbent Technologies was going to open in the near future. At this time, it is unclear if this space will open soon enough for the sorbent preparation facility to be ready for the tests at Detroit Edison or whether the facility will have to be sited elsewhere.

Plans for the Next Reporting Period

The first tasks to be completed in the next half-year relate to Phase II of the project, Equipment Preparation. The sorbent injection system must be completed, delivered to the Detroit Edison St. Clair Plant, and installed. The mercury measurement equipment must be delivered and checked out by Western Kentucky University personnel before similarly being installed. The site issue for the sorbent preparation must be resolved, the equipment delivered and assembled, and operation begun.

The Detroit Edison St. Clair Plant trial is scheduled to begin in the late summer of 2004 and should be nearing completion over the next half-year. All of the support activities must be achieved in a timely manner. The computational fluid dynamic modeling must be completed before the injection lances are installed and the trials begin. Any additional sorbent qualification testing for the cold-side sorbents must also be completed.

References

Durham, M., “Results from Four Full-Scale Field Tests of ACI for Control of Mercury Emissions,” Utility MACT Working Group, Washington DC, March 4, 2003.